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# RESEARCH MEMORANDUM

## FREE-FLIGHT-TUNNEL INVESTIGATION OF THE DYNAMIC LATERAL STABILITY AND CONTROL CHARACTERISTICS OF A HIGH-ASPECT-RATIO BOMBER MODEL WITH A SWEPTBACK-WING FIGHTER MODEL ATTACHED TO EACH WING TIP

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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# FREE-FLIGHT-TUNNEL INVESTIGATION OF THE DYNAMIC LATERAL STABILITY AND CONTROL CHARACTERISTICS OF A HIGH-ASPECT-RATIO BOMBER MODEL WITH A SWEPTBACK-WING FIGHTER MODEL ATTACHED TO EACH WING TIP

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## SUMMARY

An experimental investigation has been made in the Langley free-flight tunnel to determine the dynamic lateral stability and control characteristics of a high-aspect-ratio bomber model with a sweptback-wing fighter model attached to each wing tip with freedom in roll. This arrangement represents a configuration in which fighter protection could be provided for bombers on long-range bombing missions. By means of a mechanical linkage the outboard aileron of each fighter was operated automatically in response to the relative bank angle between the bomber and fighter to supply restoring moments to keep the fighter alined with the bomber wing. The effects of the variation in the restoring moment and of the longitudinal position of the fighter with respect to the bomber on the flying characteristics of the coupled configuration were determined in the investigation.

The results indicated that the flight behavior of this coupled configuration improved as the aileron restoring moment was increased and could be made satisfactory with values of restoring moments representative of those which could be produced by the ailerons of typical swept-wing fighter airplanes that might be used in a coupled configuration of this type. The results also indicate that the longitudinal position of the fighters with respect to the bomber had an important effect on the flight behavior of the coupled configuration. For a given restoring moment the flight behavior was worse when the fighters were attached to the bomber so that the 0.50-tip-chord points coincided, than when the fighters were in a more rearward position.

## INTRODUCTION

One serious problem at the present time is that of providing fighter protection for bombers on long-range bombing missions. It has been proposed that this problem could be solved by coupling a fighter airplane to each wing tip of a tanker airplane for in-flight refueling or to each wing tip of a bomber airplane to be carried as a parasite which could be released when fighter protection was needed. It has been suggested that by hinging the fighters to the bomber or tanker wing tips with freedom in roll, the wing-bending loads caused by the aerodynamic and mass forces of the fighters could be minimized.

Some work has been done in the Langley free-flight tunnel to study the stability and control characteristics on configurations of this type. The results of one such investigation made on a simplified bomber model with a simplified straight-wing fighter model attached to each wing tip were reported in reference 1. This study has been extended to include flight tests of a high-aspect-ratio bomber model with a $45^\circ$ sweptback-wing fighter model attached to each wing. The results of this investigation are presented herein. The outboard aileron of each fighter was automatically operated in response to the relative bank angle between the bomber and the fighter to keep the fighter alined with the bomber wing. The restoring moment about the hinge was varied by adding a chordwise extension to the outboard aileron of the fighter or by changing the gearing ratio (ratio of fighter aileron angle to bank angle of fighter with respect to the bomber). The investigation consisted of flight tests of the bomber model alone and with the fighters attached with freedom in roll with respect to the bomber. In the investigation the effects of varying the restoring moment and the longitudinal position of the fighters with respect to the bomber were studied.

The results of some other related investigations which were made in the Langley free-flight tunnel are presented in references 2 and 3.

## APPARATUS

The investigation was made in the Langley free-flight tunnel which is described in reference 4. A sketch of the bomber model with the fighters attached is shown in figure 1. The dimensional and mass characteristics of the bomber and fighter models are given in table I. A slat (see fig. 1) was installed on the bomber model wing to delay premature wing-tip stalling which was attributed to the low scale (test Reynolds number at the aileron tip of approximately 52,000) at which the tests were conducted. The effectiveness of the outboard aileron of each fighter was increased for some tests by adding $\frac{1}{4}$-inch extensions to the trailing edge of the aileron surface. This extension increased the area of the outboard aileron by 38 percent.

The fighter models were attached to the bomber by means of a hinge which provided freedom in roll of the fighters with respect to the bomber. The fighter models were restrained in yaw and pitch relative to the bomber but the angle of incidence of the fighters with respect to the bomber could be adjusted so that they tended to remain alined with the bomber at $0^{\circ}$ aileron setting. The fighters could be attached to the bomber at any of the three longitudinal positions shown in figure 2.

A mechanical linkage (fig. 3) was installed on the fighter models to deflect the outboard ailerons of the fighters in response to the relative bank angle between the bomber and fighters. The gearing ratio provided by the mechanical linkage could be varied from 1.7 to 5.4. Cushioning springs were installed in the linkage system to permit the fighters to roll with respect to the bomber after the maximum aileron deflection of the fighters was reached. The purpose of the linked ailerons was to minimize the rolling motion of the fighters relative to the bomber by producing aerodynamic forces on the fighters which tended to keep them alined with the bomber. For instance, as a fighter rotated up, the outboard aileron went up, the lift on the fighter was reduced, and the fighter therefore tended to return to its original position.

## TEST CONDITIONS

All tests were made at a dynamic pressure of approximately 3.75 pounds per square foot which corresponds to a lift coefficient of 1.0 for the bomber alone. If it is assumed that the test configuration represented a $\frac{1}{40}$-scale model of a full-scale coupled configuration, the models simulated a bomber with a wing loading of 56 pounds per square foot and a fighter with a wing loading of 34 pounds per square foot flying at an altitude of 30,000 feet.

The restoring moments about the rolling hinge produced by the linked ailerons are shown in figure 4. The maximum outboard aileron deflection of $\pm 40^{\circ}$ produced an aerodynamic restoring moment $(M_A)$ of 0.06 and 0.114 foot-pound for the ailerons of the isolated fighter models with the $\frac{1}{4}$-inch extensions off and on, respectively. The vertical portion of the restoring-moment curves (fig. 4) represents the preload in the cushioning springs $(M_P)$ that had to be overcome before the fighters could bank to an angle greater than that which corresponded to $40^{\circ}$ aileron deflection. After the preload was overcome the fighters could reach higher angles by compressing the cushioning springs. The restoring moments provided by compression of the springs $(M_S)$ are shown by the constant slope above the vertical portion of the curves. The maximum angle of bank that could be reached by the fighters (springs fully compressed) was about $40^{\circ}$ for a gearing ratio of 4.0.

In order to obtain some indication of the magnitude of the aileron restoring moment in terms of what might be expected for a full-scale fighter, the aileron effectiveness (rate of change of rolling-moment coefficient with aileron deflection, $C_{l_{\delta_a}}$) of the fighter models with and without the $\frac{1}{4}$-inch aileron extension were obtained from force tests. The value of $C_{l_{\delta_a}}$ was 0.0012 with the extension on and 0.0006 with the extension off. The value of $C_{l_{\delta_a}}$ with the extension off appears to be somewhat lower than would be expected for an aileron of this size. The values of $C_{l_{\delta_a}}$ with extensions off and on represent the approximate range of values of this factor for sweptback fighter airplanes. It appears, therefore, that the restoring moments about the hinge produced by the outboard ailerons of the fighter models could be produced by the outboard ailerons of sweptback fighter airplanes which might be used in a configuration of this type. For a more exact interpretation of the model results in terms of the full-scale airplane configuration, the restoring moment produced by the cushioning springs as well as that produced by the aileron should be considered. For this purpose information similar to that shown in figure 4 for the model should be available for the particular airplane and automatic control arrangement under consideration.

The static lateral stability characteristics of the bomber model alone and of the coupled configuration as determined from force tests are shown in table I. Results of additional force tests indicated that there was a negligible effect on the static lateral stability characteristics of sealing the gap between the bomber and fighter wing tips. For convenience, all flight tests of the coupled configuration were made with the gap unsealed.

Flight tests were made of the bomber alone and of the bomber with the fighters attached with freedom in roll. In the flight tests made with the fighters attached, the effects of varying the restoring moment were investigated. The effects of varying the longitudinal position of the fighters with respect to the bomber for the three positions shown in figure 2 were also investigated because a preliminary analysis indicated that this variable might be an important factor affecting the flight behavior of a configuration of this type. For example, since the aerodynamic center of the sweptback fighter was located well forward of the most convenient attachment point (0.50-chord stations of bomber and fighter tip chords coincide), it was believed that any random change in the angle of attack of the fighter caused by a gust or control disturbance would produce a pitching moment which (because of the flexibility of the bomber wing) would cause a further angle-of-attack change of the fighter. This change in angle of attack would of course be expected to affect the flapping motion of the fighter (rolling motion of the fighter with respect to the bomber). Since the center of gravity of the fighter was also well forward of the bomber wing tip, changes in angle of attack could also be produced by the pitching moment resulting from a normal acceleration of the fighter. With the fighter in the rear position (see fig. 2) the aerodynamic center of the fighter was located at the same longitudinal position as the attachment hinge (0.50-tip-chord point of bomber) and the center of gravity of the fighter was only slightly forward of the hinge (0.25-tip-chord point of bomber).

In all of the flight tests made with the fighters attached, the pilot paid particular attention to the flapping of the fighters and to the effect of this flapping on the general flight behavior of the coupled configuration. The flapping motions of the fighters were also determined quantitatively from motion-picture records.

The various conditions investigated in the flight tests of the coupled configuration are listed in table II.

## RESULTS AND DISCUSSION

### Interpretation of Results

The rolling motions of the bomber in controlled flight and the corresponding angles of bank of the attached fighter models (measured with respect to the horizontal) are shown in figure 5. Since these records were read within an accuracy of $\pm 0.5^{\circ}$ and no attempt was made to fair smooth curves through the scatter of points, any abrupt motion falling within these limits may not represent the actual motions of the models. In some cases the fighter-model rolling motions are displaced from those of the bomber because it was difficult to keep the fighters trimmed to zero bank with respect to the bomber. It was also difficult to keep the fighters trimmed so that the ailerons were at exactly

$0^{\circ}$ deflection when the fighters were at $0^{\circ}$ bank. The data of figure 4, therefore, cannot be used to obtain accurate estimates of the restoring moments for a given condition. These data can be used, however, to obtain a general indication of the variation of restoring moment with fighter bank angle.

In order to identify the various test conditions in terms of restoring moment, a gearing factor was determined from the restoring-moment data for each test condition by the method shown in figure 4. Although this gearing factor is only an average value and not an exact measurement of the restoring moment over the entire fighter bank-angle range, it does provide an indication of the relative restoring moment for the various conditions.

It appears from the records of figure 5 that the motions of the models were somewhat erratic. These motions, however, are considered typical of the motions of the relatively small-size models flown in the free-flight tunnel with the flicker-type control system (full on - full off). In some cases the control applications shown in the records of figure 5 were applied by the pilot to position the model in the tunnel rather than to maintain a wing-level attitude. Experience has shown that the results of flight tests in this tunnel are normally of a conservative nature because the type of control used and the high angular velocities of the small models prevent the pilot from controlling the model as smoothly as would be possible with the proportional control of a full-scale airplane. In the present investigation the banking motions of the bomber alone were of the same general magnitude as the motions of the bomber shown in the records of figure 5. Despite these rather large banking motions the flight behavior of the bomber alone was considered representative of that of an airplane having normally good stability and control characteristics. It would be expected, therefore, that the motions of a full-scale coupled airplane configuration would be much less erratic than those indicated by the flight records presented in figure 5.

## Effect of Gearing Factor

Increases in the gearing factor appeared to improve the flight behavior in all cases. The condition with the fighters located in the rearward position and with the highest gearing factor tested (0.018) was considered by the pilot to have satisfactory stability and control characteristics. The flight behavior for this condition was judged by the pilot to be almost as good as that for the bomber alone, although more aileron control was required with the fighters attached because of the increased rolling inertia and damping in roll. When the gearing factor was decreased to 0.013 (rearward fighter position) the flight behavior became worse and the model was considerably more difficult to fly because the flapping motions of the fighters were too lightly damped. When the gearing factor was decreased to 0.006 the flight behavior was considered to be entirely unsatisfactory because it was almost impossible for the pilot to maintain flight.

The same effects on the flight behavior of decreasing the gearing factor were noted in the flights made with the fighters attached in the mid or forward positions. The flight behavior with a gearing factor of 0.008 or 0.011, with the fighters in the mid or forward positions, respectively, was similar to that for the condition with the fighters in the rearward position and with a gearing factor of 0.006.

With the minimum gearing factor required to maintain flight, the flapping motions of the fighters were very erratic and lightly damped for all longitudinal positions of the fighters. This flapping was most noticeable after a gust or control disturbance. It appeared that because of the low damping these disturbances tended to keep the fighters constantly in motion and often caused the model to go out of control and crash. At times the flapping imparted a small-amplitude, high-frequency oscillation to the coupled configuration. This oscillation, which was similar to that obtained in the free-flight-tunnel fuel-sloshing investigation reported in reference 5, was apparent only with the low gearing factors where the fighters were continually in motion. The high-frequency oscillation, which was superimposed on the normal, longer-period motions of the model, was very annoying to the pilot and seemed at times to reinforce the normal model motions so that the resultant flight was very jerky and erratic. An analysis of these results would seem to indicate that the flight behavior of a full-scale configuration of this type with low gearing factors would be bad in gusty weather.

It is believed that a comparison of the flapping motions presented in the records of figure 5 for the various conditions might be misleading in some cases. For example, the approximately constant amplitude flapping of the fighters shown in the last portion of the records for a gearing factor of 0.008 with the model in the rearward position was evidently caused by the pilot unintentionally reinforcing the oscillation of the fighter models by applying the abrupt aileron control at about the same frequency as the natural frequency of the fighter models. This record, therefore, is not considered to be significant in a comparison of the effects of gearing factor or of fighter position.

## Effect of Longitudinal Position of Fighters

The effect of changing the longitudinal position of the fighters from the forward to the rearward position was to improve the flight behavior of the coupled configuration. A gneral indication of this effect is shown by the records of figure 5 which show that less gearing factor was required to maintain flight with the fighters attached in the rearward position than was required with the fighters in the mid or forward position. The effect of longitudinal position of the fighters on the flight behavior was not pronounced when the gearing factor was high (0.013 or 0.018) because flights could still be maintained easily even with the fighters in the forward position. At some lower values of gearing factor, however, the effect of longitudinal position was much more pronounced because with the fighters in a forward position the configuration became unflyable. In these cases the fighters would not remain alined with the bomber because of insufficient gearing. Even slight disturbances caused relatively large flapping motions of the fighters which sometimes caused the coupled configuration to go out of control and crash.

As was pointed out previously, the principal effect of changing the longitudinal position of the fighter is to change the magnitude of the random pitching moments of the fighter which (because of the bomber wing flexibility) would cause changes in the angle of attack of the fighter. It appears, therefore, that the poorer flight behavior obtained with the fighter models in the forward position was caused by the larger random changes in fighter angle of attack in this position.

The pilot had the impression that, for a given gearing factor, the flapping of the fighters with respect to the bomber was worse when the fighters were attached in the forward position. It appears from the records of figure 5 that the fighter motions damp more rapidly after a disturbance when the fighters are attached in the rear position than when attached in the forward position, but the general magnitude of the flapping motion does not appear to be appreciably different for the various flight conditions. Apparently the pilot's opinion of the flapping motions was influenced more by the damping of the fighter motion than by the magnitude of the bank angles.

## CONCLUDING REMARKS

The results of the investigation made in the Langley free-flight tunnel showed that the dynamic lateral stability and control characteristics of a high-aspect-ratio bomber with a sweptback fighter attached to each wing tip improved as the aileron restoring moment was increased. These results indicated that the flight behavior of such a configuration could be made satisfactory with values of restoring moments representative of those which could be produced by the ailerons of typical swept-wing fighter airplanes of current design that might be used in a coupled configuration of the type used in this investigation. The results also indicated that the longitudinal position of the fighters with respect to the bomber had an important effect on the flight behavior of the coupled configuration. For a given restoring moment the flight behavior was worse when the fighters were attached to the bomber so that the 0.50-tip-chord points coincide than when the fighters were in a more rearward position.

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TABLE I

DIMENSIONAL, MASS, AND STATIC LATERAL STABILITY CHARACTERISTICS

| | Bomber model | One fighter model | Coupled configuration |
|---|---|---|---|
| Mass characteristics | | | |
| Weight, lb | 4.87 | 0.65 | 6.17 |
| Wing loading, lb/ft$^2$ | 3.74 | 2.26 | 3.30 |
| Radius of gyration about longitudinal body axis, spans | 0.15 | ---------- | [a]0.31 |
| Radius of gyration about vertical body axis, spans | 0.21 | ---------- | [a]0.39 |
| Inertia of fighter model about hinge, pound-in$^2$ | ---------- | 23.00 | -------- |
| Center of gravity, percent M.A.C. | 0.25 | 0.25 | -------- |
| Aerodynamic center, percent M.A.C. | ---------- | 0.36 | -------- |
| Dimensional characteristics | | | |
| Wing: | | | |
| Airfoil section | Rhode St. Genese 35 | Rhode St. Genese 35 | -------- |
| Span, in. | 45.00 | 11.15 | [b]68.55 |
| Area, sq in. | 187.20 | 41.38 | 269.96 |
| Aspect ratio | 10.76 | 3.00 | -------- |
| Taper ratio | 0.25 | 0.50 | -------- |
| Mean aerodynamic chord, in. | 4.66 | 3.85 | -------- |
| Sweepback 0.25c, deg | 12 | 45 | -------- |
| Aileron. | | | |
| Area, percent wing area (one aileron) | 3.77 | 5.26 | -------- |
| Chord, percent wing chord | 30.00 | 25.00 | -------- |
| Span, percent wing span (one aileron) | 17.92 | 23.50 | -------- |
| Fuselage: | | | |
| Length, in. | 32.60 | 18.07 | -------- |
| Diameter, in. | 2.50 | 2.00 | -------- |
| Fineness ratio (Length/Diameter) | 13.04 | 9.04 | -------- |
| Vertical tail: | | | |
| Airfoil section | NACA 0012 | NACA 0012 | -------- |
| Span, in. | 6.31 | 2.46 | -------- |
| Area, percent wing area | 13.50 | 12.45 | -------- |
| Aspect ratio | 1.58 | 1.18 | -------- |
| Taper ratio | 0.33 | 0.47 | -------- |
| Horizontal tail: | | | |
| Airfoil section | NACA 0009 | NACA 0012 | -------- |
| Span, in. | 15.00 | 4.58 | -------- |
| Area, percent wing area | 22.09 | 16.85 | -------- |
| Aspect ratio | 5.50 | 3.00 | -------- |
| Taper ratio | 0.38 | 0.50 | -------- |
| Tail length ($\frac{1}{4}$- chord point of wing mean aerodynamic chord to rudder hinge line), in. | 15.47 | 8.03 | -------- |
| Static lateral stability characteristics | | | |
| Directional-stability parameter, yawing-moment coefficient due to sideslip, $C_{n_\beta}$, per deg | [a]0.0023 | ---------- | [c]0.0015 |
| Effective-dihedral parameter, rolling-moment coefficient due to sideslip, $C_{l_\beta}$, per deg | [a]-0.0009 | ---------- | [c]-0.0006 |
| Effective-lateral-force parameter, lateral-force coefficient due to sideslip, $C_{Y_\beta}$, per deg | [a]-0.013 | ---------- | [c]-0.010 |

[a]Based on span of bomber.
[b]Includes gap for hinge installation.
[c]Based on span of coupled configuration.

TABLE II

FIGHTER CONFIGURATIONS TESTED

| Condition | Gearing ratio | Aileron extension | Fighter position | Gearing factor |
|---|---|---|---|---|
| 1 | 5.4 | On | Rearward | 0.018 |
| 2 | 5.4 | On | Forward | .018 |
| 3 | 4.0 | On | Rearward | .013 |
| 4 | 4.0 | On | Mid | .013 |
| 5 | 4.0 | On | Forward | .013 |
| 6 | 3.4 | On | Forward | .011 |
| 7 | 4.0 | Off | Rearward | .008 |
| 8 | 4.0 | Off | Mid | .008 |
| 9 | 1.7 | On | Rearward | .006 |

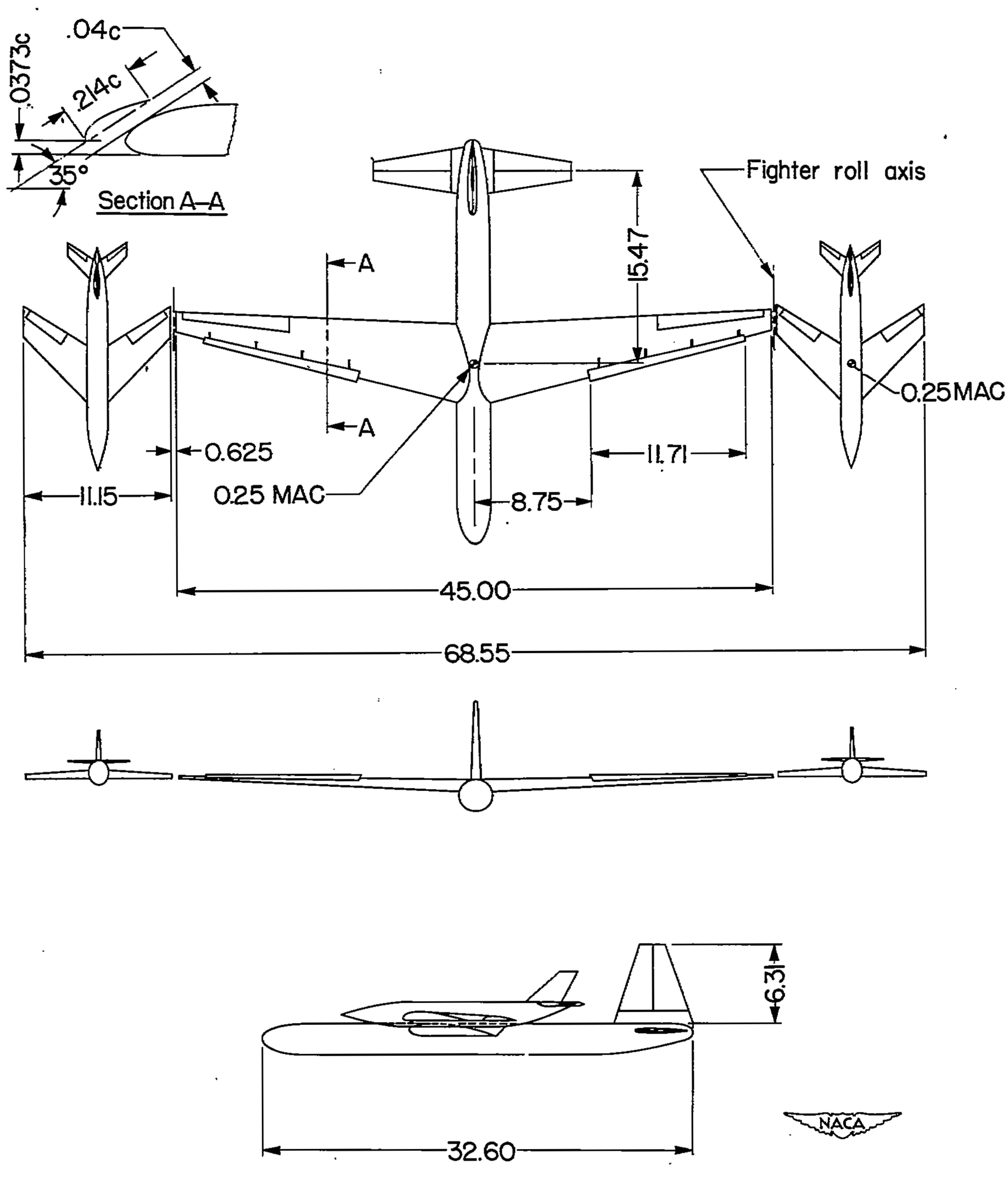


Figure 1.- Three-view sketch of high-aspect-ratio bomber model with fighter models attached. All dimensions are in inches.

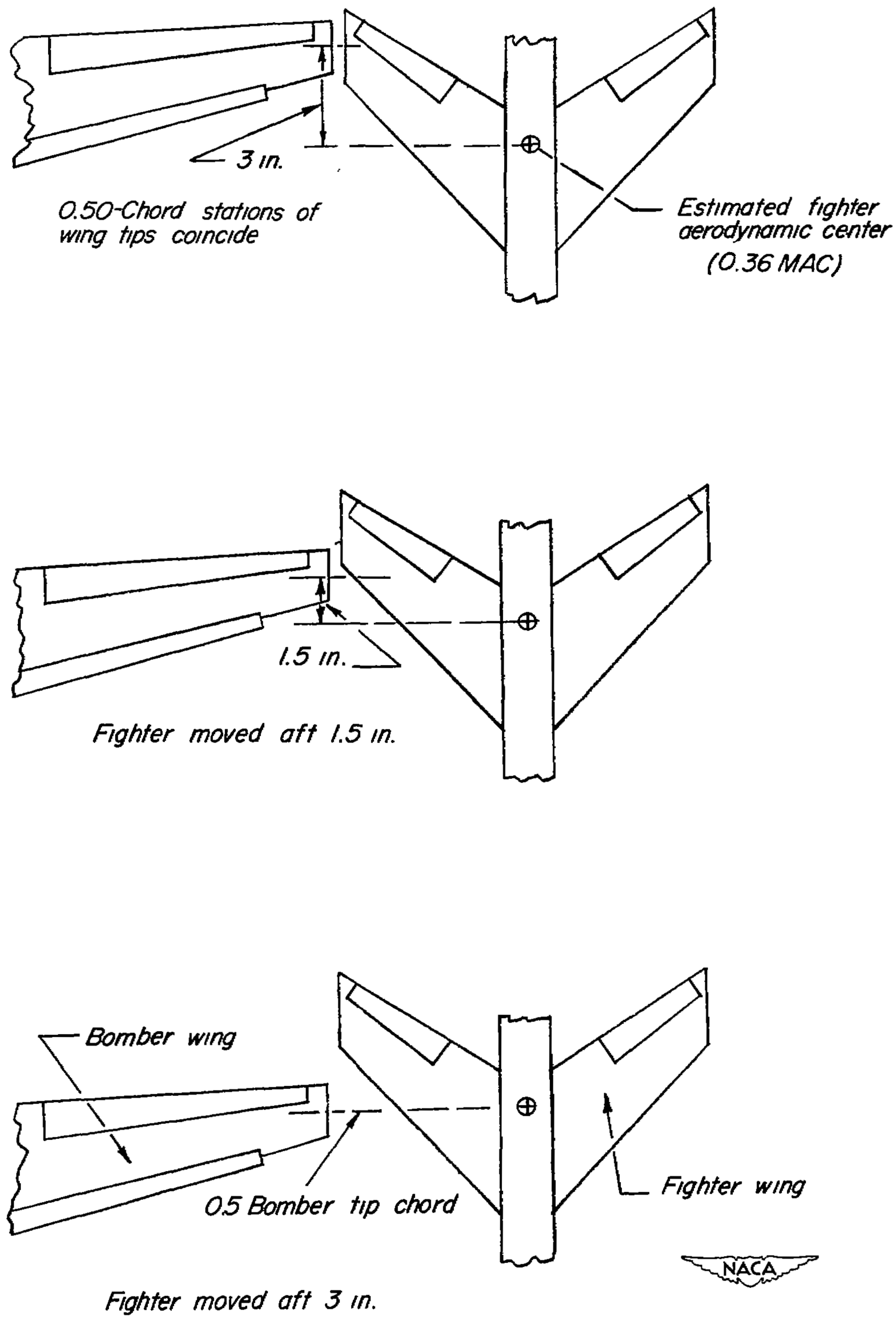


Figure 2.- Longitudinal positions of fighter models tested.

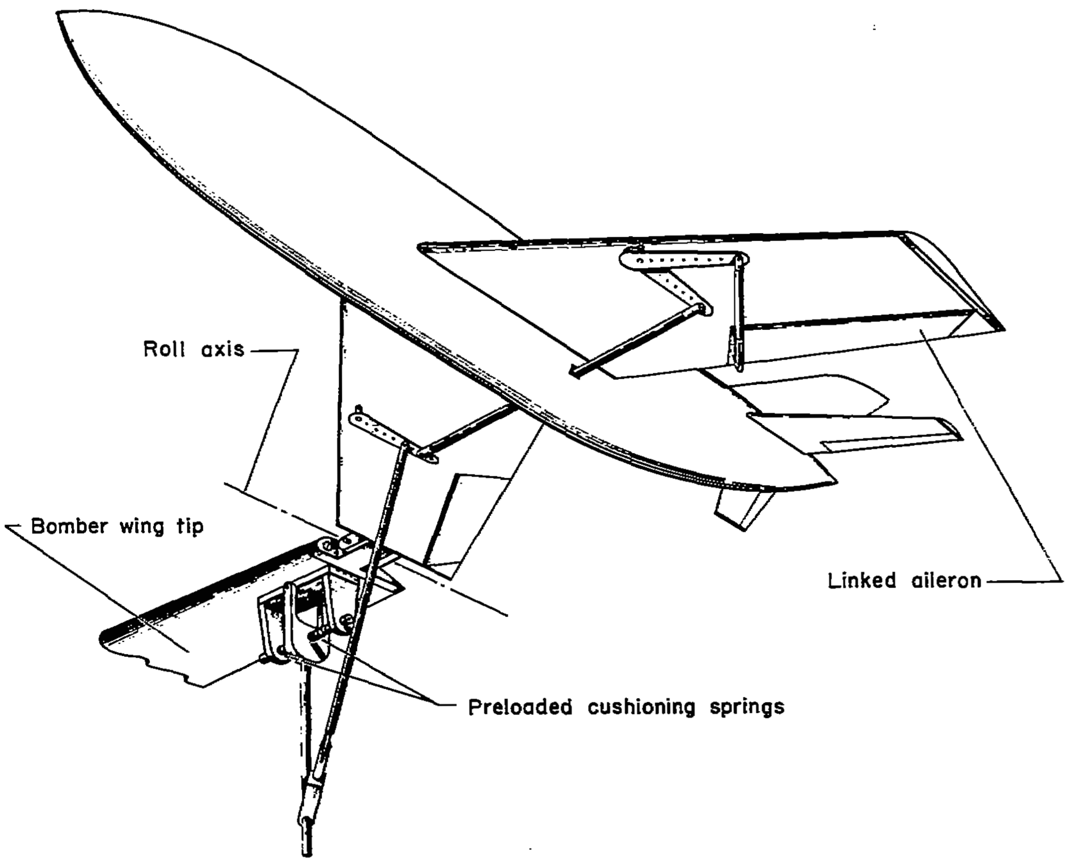


Figure 3.- Sketch of linkage system used to deflect the outboard aileron of fighter model in response to the angle of bank of the fighter with respect to the bomber.

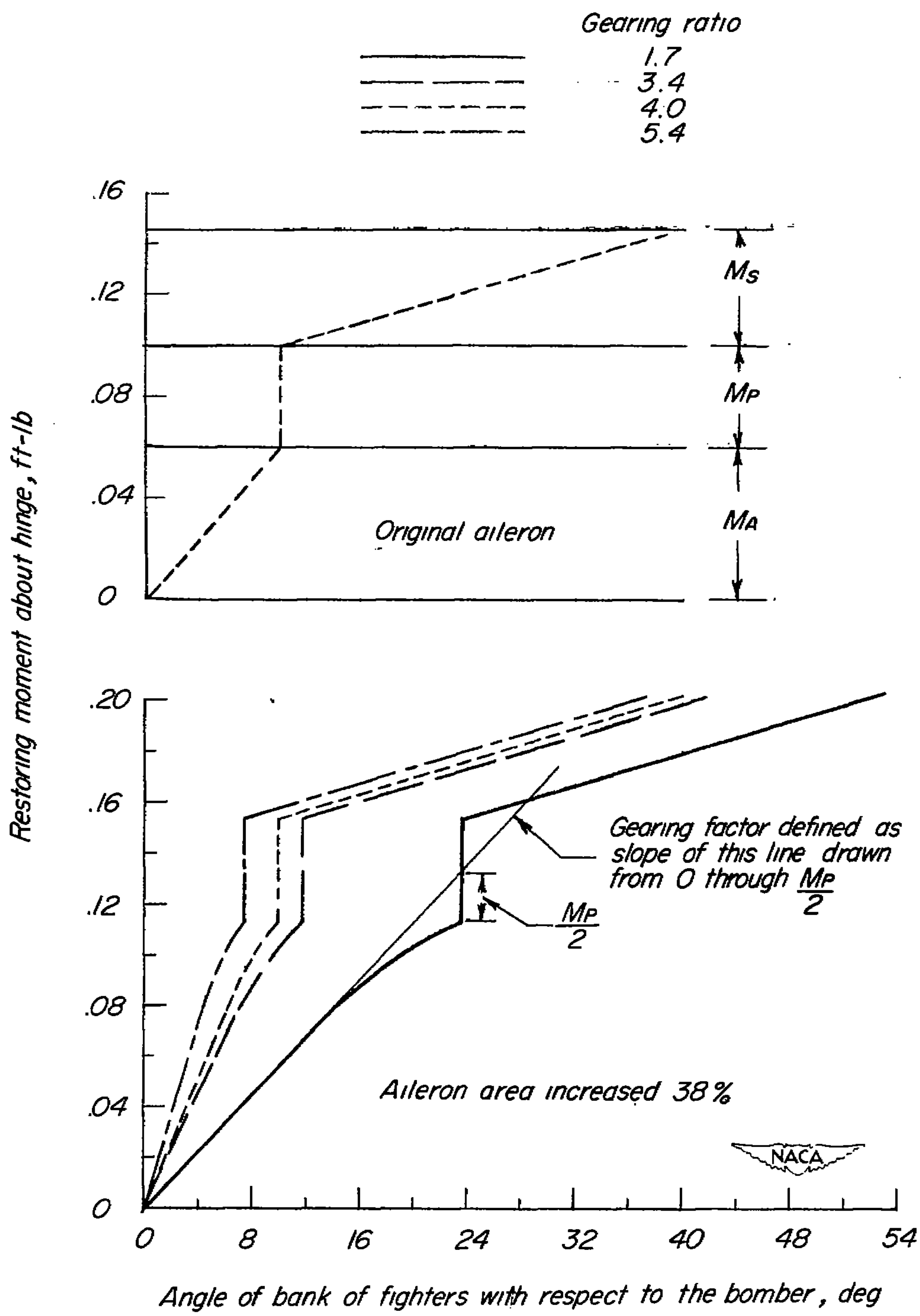


Figure 4.- Fighter restoring moments used in the investigation.

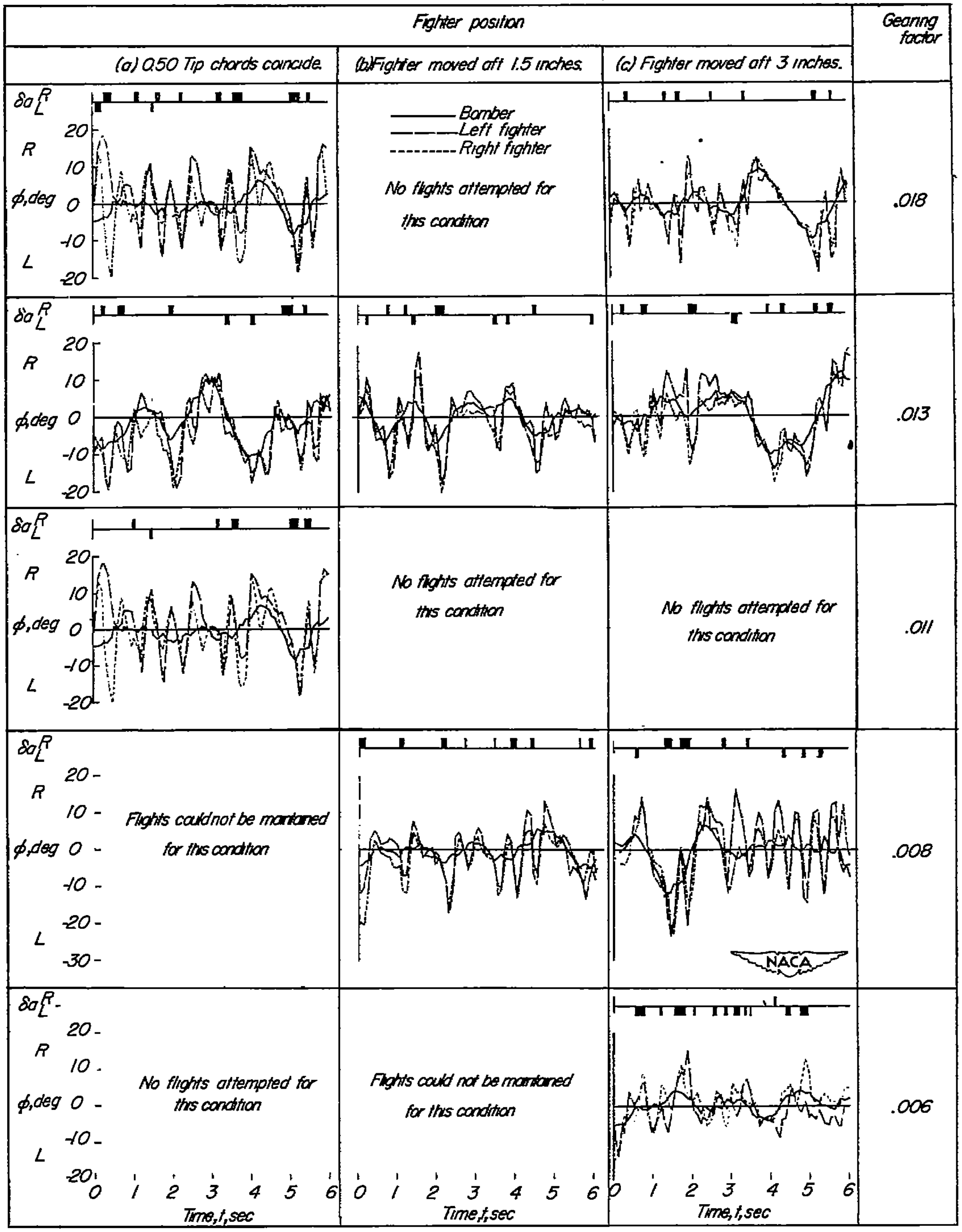


Figure 5.- Time histories of bomber and fighter bank angles $\phi$ and direction of applied aileron control $\delta_a$ for three longitudinal positions of the fighters with respect to the bomber. (R, right; L, left.)